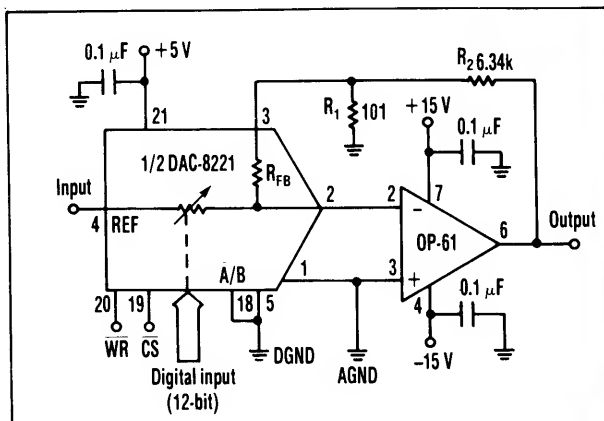# Add Programmable Gain, Attenuation

by James Wong

By adding two resistors to the output-amp feedback loop of a current-output digital-to-analog converter (DAC), both gain control and attenuation control can be achieved *(Fig. 1)*. This digitally programmable amplifier produces gain and attenuation in the range of 1/64 to 64. The circuit gets its range from a 12-bit CMOS DAC.
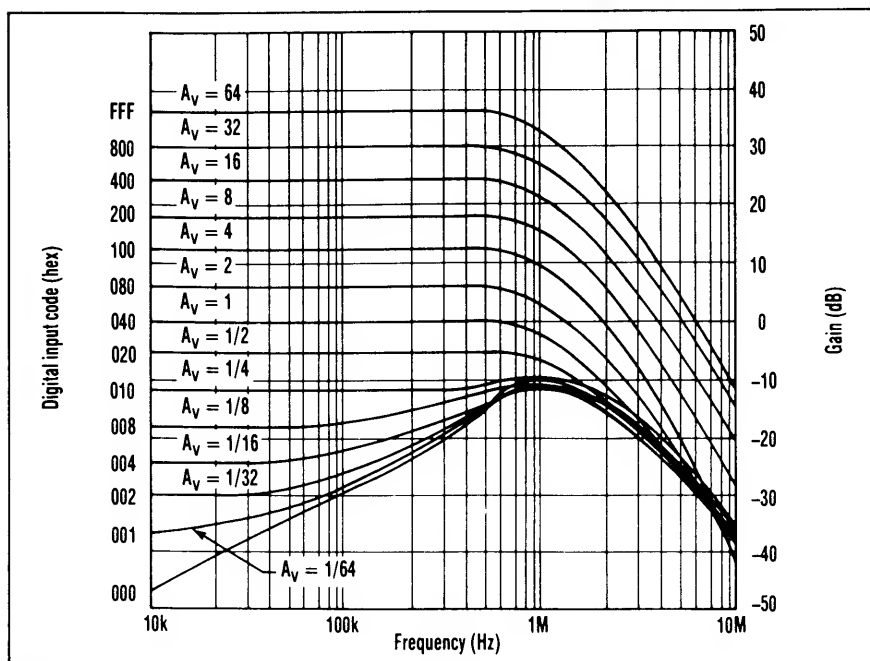
The design works because the transfer function from the DAC's input to its output is purely voltage attenuation. Connecting R_1 and R_2 in a "T" configuration inside the output amp's feedback loop produces a voltage gain from the resistor junction to the output. If R_1 is much less than R_{FB} (11 kΩ in this example), the gain produced nearly equals $1 + (R_2/R_1)$, or 64. The result is a programmable gain amp with a transfer function of

$$A_V = -(D/4096)(64),$$

where D represents the DAC's binary-weighted digital code. Of course, the added gain of the T-network increases the circuit's noise gain. Therefore, it's important to choose first a low-noise amplifier.

By using a low-noise, high-frequency op amp, such as the OP-61, the circuit will have a wide bandwidth performance even at high gain settings. The circuit's frequency response can be plotted at different gain settings *(Fig. 2)*. At high gains, the amp has a 1-MHz bandwidth.□

1. BY adding R_1 and R_2 in the feedback loop around a DAC, the circuit functions as a digitally-programmable amp. The gain or attenuation is variable over the range of 1/64 to 64. The resistors are connected in a T-configuration.

2. GAIN IS PLOTTED versus frequency for various digital inputs of the DAC. The amplifier has a 1-MHz bandwidth at high gains, but it drops for gains below 1/4.